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16. ABSTRACT
An evaluation of two proposed modifications to the sand equivalent test procedure is reported. Tests were randomly performed on samples with varying moisture contents and curing times. Testing was also done on identical samples at various temperatures. It was concluded that temperature changes affect each material differently but that all materials are affected predictably by a standardized moisture condition. It is recommended that ASTM use prescribed temperature limits and that alternate preparation methods, moist or oven-dried, be included in the test procedure.

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HIGHWAY RESEARCH REPORT

SAND EQUIVALENT TEST INVESTIGATION OF PROCEDURAL MODIFICATIONS

68-18

STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 632834

Prepared in Cooperation with the U.S. Department of Transportation, Bureau of Public Roads January, 1968

STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

5900 FOLSOM BLVD., SACRAMENTO 95819

January 1968
Final Report
M & R No. 632834
F-4-14

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a Research Report titled:

SAND EQUIVALENT TEST INVESTIGATION

OF

PROCEDURAL MODIFICATIONS

Travis Smith
Principal Investigator

A. D. Hirsch and Charles A. Frazier
Co-Investigators

Assisted By
A. Y. Lee
J. Vail

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

REFERENCE: Smith, T. W., and Frazier, C. A., "Sand Equivalent Test Investigation of Procedural Modifications" State of California, Dept. of Public Works, Division of Highways, Materials and Research Department, Research Report 632834 Jan. 1968.

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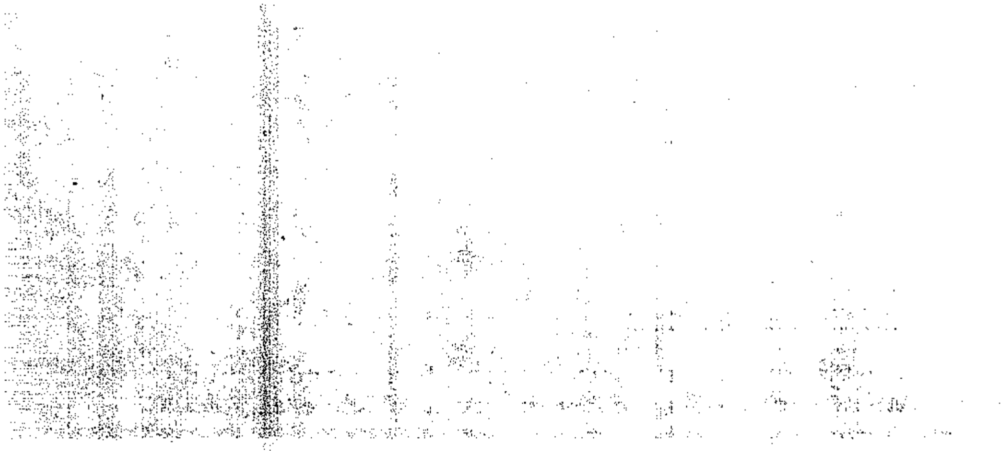
KEY WORDS: Aggregates, Fine Aggregates, Testing, Test Methods, Sand Equivalent Test, Moisture Content, Temperature.

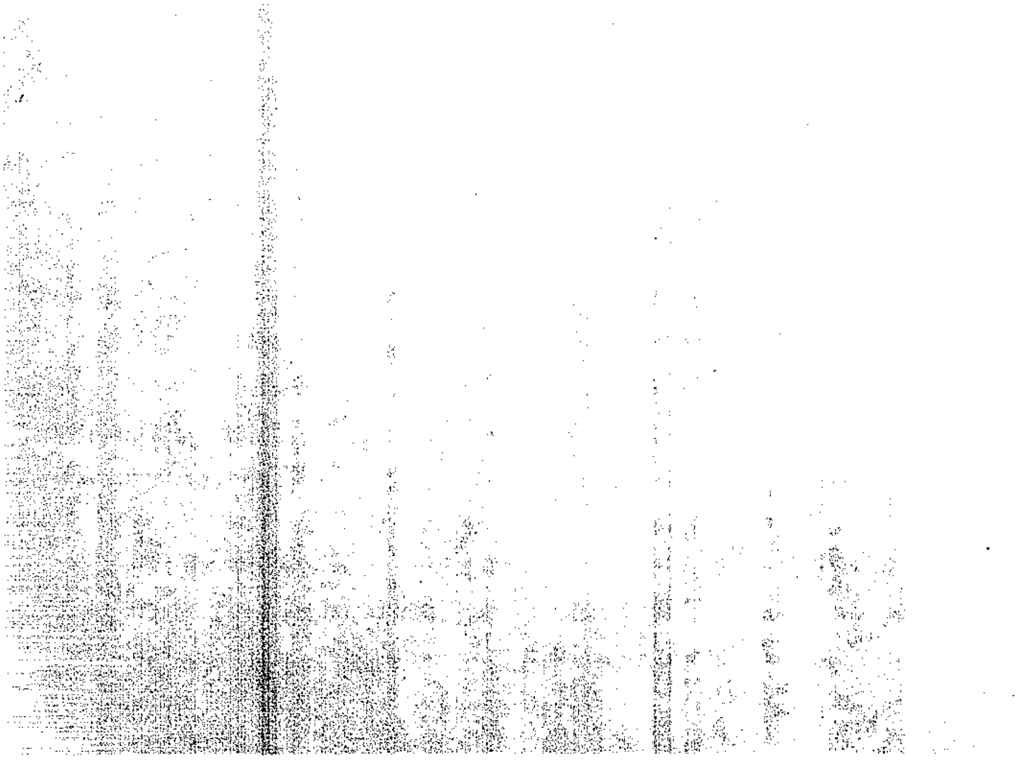
Acknowledgments

The researchers wish to express their appreciation to the individuals who participated in the preparation and testing of the many duplicate samples necessary for this project. Special thanks are extended to Messrs. W. D. Hill of the Oregon Highway Department and W. G. O'Harra of the Arizona Highway Department for their helpful suggestions and review of this report.

This work was requested by the ASTM Task Force on "Sand Equivalent Value of Soils and Fine Aggregates" and was done by the California Materials and Research Department under Work Program HPR 1(4), in cooperation with the U.S. Department of Transportation, Federal Highway Administration, U.S. Bureau of Public Roads.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.





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Introduction

The sand equivalent test (S. E.) has proven to be a convenient and rapid method for the field quality control of untreated aggregates in highway construction. Many state highway departments presently use it as a primary control test on a variety of products ranging from subbases to PCC sands. It has been adopted by the American Association of State Highways Officials (AASHO) and is a tentative method of the American Soceity for Testing and Materials (ASTM).

In January, 1965, Mr. J. L. Beaton, Materials and Research Engineer of the California Division of Highways, accepted the chairmanship of an ASTM Task Force to develop a (revised) tentative method of test for "Sand Equivalent Value of Soils and Fine Aggregates." The other members of this Task Force are Mr. W. G. O'Harra, Engineer of Materials of the Arizona Highway Department and Mr. W. D. Hill, Foundation Engineer of the Oregon State Highway Department.

As a result of their initial considerations, the Task Force concluded that further study was necessary on proposed modifications to the test method in two areas, moisture control of the test specimen and temperature control of the working solution.

It had been proposed that the test method be modified to allow the use of moist samples, saving the time and trouble of oven-drying the test specimen. It was also proposed that the temperature control ($72 \pm 5^{\circ}$) on the S. E. working solution be waived or the limits widened to make it easier to attain in the field. Information then available on the effects of the two proposed modifications indicated that the sand equivalent value generally decreased as the moisture content increased or the temperature of the working solution decreased. The available information was insufficient to draw definite conclusions, however.

At the request of the ASTM Task Force on Development of the Sand Equivalent Test, a BPR participating research project to determine the effect of the proposed procedural modifications on the Sand Equivalent test was initiated by the Materials and Research Department of the California Division of Highways.

Fifteen samples were randomly selected for use in the study, three each in five ranges of S. E. from 20 to 90. The initial S. E. values for these materials were determined by the California (oven-dry) method.

Testing was performed in two phases. In Phase I each of the fifteen materials was tested at all combinations of three moisture conditions and four curing times plus oven-dry, air dry, and extended saturation conditions. In Phase II each of the fifteen samples was tested at five temperature conditions and two moisture conditions, oven dry and "cast" point moisture, with an overnight cure time. All variations of the sand equivalent test in each phase were run in triplicate and completely randomized except for temperature control, which could not be readily varied. All samples were batched from a 1000 to 1500 gram portion of the material to be tested by pushing the S. E. measuring tin through a cone of material formed by the operator after mixing with a trowel. This method was necessitated by the use of moist test samples which could not be split by normal methods. Results using this technique were comparable with a control test run on each material by the California method. Reproducibility through both phases was good.

A detailed explanation of sample selection and testing methods is included in the body of the report.

Conclusions

The following conclusions are justified by the results of this study.

1. Higher ambient temperature produced higher sand equivalent values. The amount of change in S. E. between temperatures varied with each material under test and was not consistent within a given sand equivalent range. A valid application of the test will, therefore, require temperature control such as that included in the California method.

> "Control - The temperature of the working solution should be maintained at 72 ± 5 F during performance of this test. If it is not possible to maintain the working solution at this temperature, samples should be frequently submitted to a laboratory where proper temperature control can be maintained."

Although impractical for routine testing, it would be possible to establish temperature correction curves for each material being tested when proper temperature control is not feasible. It is emphasized that no general temperature correction curve could be developed - even for a narrow range of sand equivalent values.

2. Moist test specimens produced lower sand equivalent values than the corresponding oven-dry specimen with almost no exceptions. However, as with temperature, the difference in results is not constant even for a given range of materials, but is dependent on the character of the material itself.

3. Results of analysis of variance on the moisture phase of testing indicated that between the "fluff" point and "cast" point moisture conditions, no significant differences in the test result were produced by increased moisture or by lengthened curing times.

4. Reproducible results can be obtained by using either the oven-dried or moist-sample preparation methods, however, certain precautions must be observed with each method. If the oven-dried preparation method is used, considerable care must be exercised in splitting the sample to insure that the test specimen is representative of the material to be tested.

If the test specimen is prepared by the moist method, the material as received, should be at a specified moisture condition or wetter (say, the "fluff" point). Test specimens may then be prepared and the test performed immediately. If the material is drier than the condition specified, water will have to be added to the material and a mixing and curing time will be necessary. If a dual specification encompassing both the wet and dry methods of sample preparation were utilized, it would be necessary to determine the appropriate correction for each material since a standard correction does not appear possible. Either method can be employed with equal confidence, however.

Sample Selection

Because the S.E. test is used for quality control on many different materials, this investigation covered the range of S.E. values from approximately 20 (subbase material) to 90 (PCC Sands). Previous analyses had shown that the greatest testing error occurred in the 60+ S.E. range with the error declining at higher or lower sand equivalent values. Because of this known variation in testing accuracy, three materials were randomly selected in each of five sand equivalent ranges. These materials were tested by the California (oven-dried) method and the following sand equivalent values were obtained.

Range	A	22	26	27
"	B	36	40	40
"	C	55	61	62
"	D	68	73	76
"	E	90	91	94

Each material was then split into two equal parts, one for each phase of the testing program. All materials to be tested were in an air dry condition prior to alteration of the moisture content.

Testing and Discussion of Test Results

Phase I. As was mentioned earlier in this report, in Phase I each of the fifteen materials was tested at all combinations of three moisture conditions and four curing times plus oven-dry, air-dry and extended saturation moisture conditions. In lieu of preparing the test specimen to a fixed moisture content, the following criteria were used to establish a moisture condition which would be dependent on the characteristics of the material being tested:

Fluff Point. The moisture content that will result in sufficient cohesion in the material to barely form a cast when firmly squeezed in the hand. The cast will break with any sudden or jarring movement.

Cast Point. The moisture content that will give enough cohesion in the material to form a firm cast when firmly squeezed in the hand. At this condition the cast will remain intact after the hand is fully open and require an obvious jar or touch to break it.

Saturation. The moisture content at which the maximum amount of moisture has been added to the material while showing no visible free water.

Four curing times, 1/4, 1/2, 1, and 2 hours, were used in this phase of testing. Test specimens prepared to the three moisture conditions noted above were prepared and tested in triplicate at each of the four curing times. In addition to the 12 moisture-curing time combinations, each material was also tested in an oven-dried condition, air-dried condition, and a 7 day cure saturated condition.

Standard analysis of variance technique was used for determining the effect of all moisture conditions, curing times, and the various interactions on the sand equivalent value.

Without exception, material from all five (5) ranges decreased in sand equivalent as moisture content increased from the dry to the "fluff" state. With the exception of Range A samples, the only significant variations in sand equivalent test results between the "fluff" and saturation states were between the different materials used in this investigation and those interactions involving the materials. Change in curing time had no significant effect on test results. See Tables 1 and 3 for a statistical summary.

In the A group, all the materials contained relatively high percentages of clay. Any additional moisture beyond the "cast" point had a significant effect on the sand equivalent value obtained. As shown on Figure 1, it appears that increasing the moisture prior to curing tends to produce increasing sand equivalent values. This characteristic is the reverse of what was expected by the investigator. It was believed that the additional moisture present during the curing period would penetrate this clay portion of the sample, releasing more unflocculated clay particles into the clay column during the test. No explanation is apparent for this reverse trend on the Group A samples.

To summarize, all materials tested showed a significant reduction in S.E. between the dry and the "fluff" state. There were no significant differences in test results for any of the samples between the "fluff" and "cast" point moisture conditions and only the low range (Group A) show any significant difference between the "cast" point and saturated conditions. Therefore, it samples are tested between "fluff" point and "cast" point, any variation in test results should be within the range of normal testing error.

Phase II. The same fifteen samples used in Phase I were also tested in triplicate for effects of ambient temperature on the sand equivalent result. Each sample was tested at five separate temperatures from 40°F to 112° F. in 18° increments (40°, 58°, 76°, 94°, 112°). The two moisture conditions used were oven-dry and "cast" point.

Based on the results of Phase I testing, it was concluded that precise moisture control of the moist test sample was not require in the temperature effects phase. For this reason the moist samples were prepared at approximately the "cast" point moisture condition.

All testing on this phase was done in a small, temperature controlled chamber. Samples were prepared one day in advance of testing and all components of the test were stabilize overnight at the new temperatures. The order of testing was completely randomized except for temperature, which was held constant during any given testing day and randomly varied during the ten days required to complete this phase of testing. All specimens under each condition were tested in triplicate.

Analyses of test data, as summarized in Tables 4 and 5, indicate that temperature variation has a highly significant effect on test values obtained on oven dry samples with midrange (Range B & C) sand equivalents and on all moist materials except those in the lowest range (Range A). An examination of Figures 2 and 3 and Tables 1, 4 and 5 shows that the mid-range values have a highly significant lineal trend of increasing sand equivalent values as the temperature increases. This trend of increasing S.E. values is less marked in the extreme ranges. Furthermore, the trend is confounded by the highly significant S x T interactions, indicating that the trend is not the same between materials within the same range. This was found to be true under both oven-dry and moist conditions.

Based on these findings, it appears that the relationship between sand equivalent test result and temperature could be determined for a single material, but this relationship would probably not be valid for another material of the same quality as measured by the sand equivalent test.

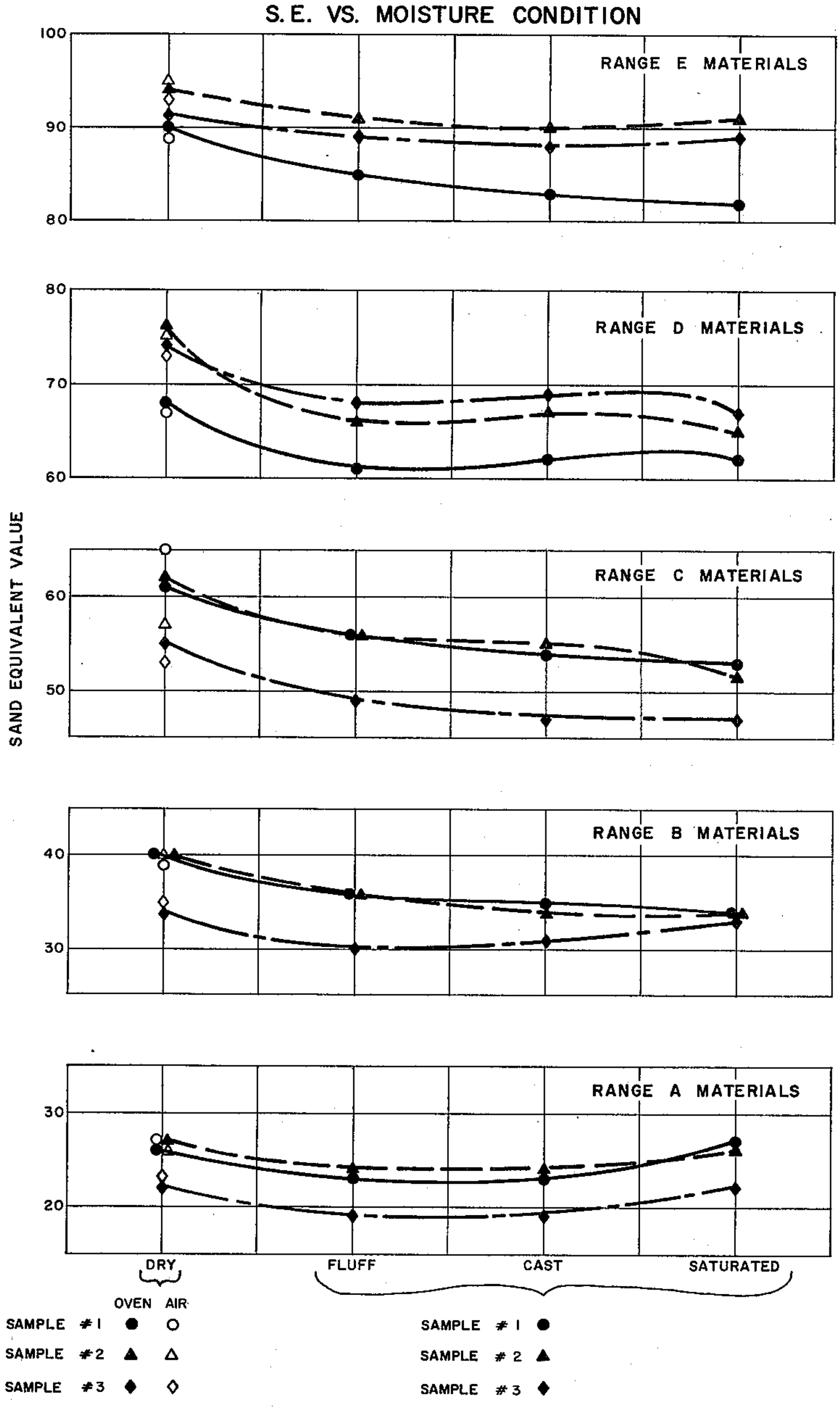
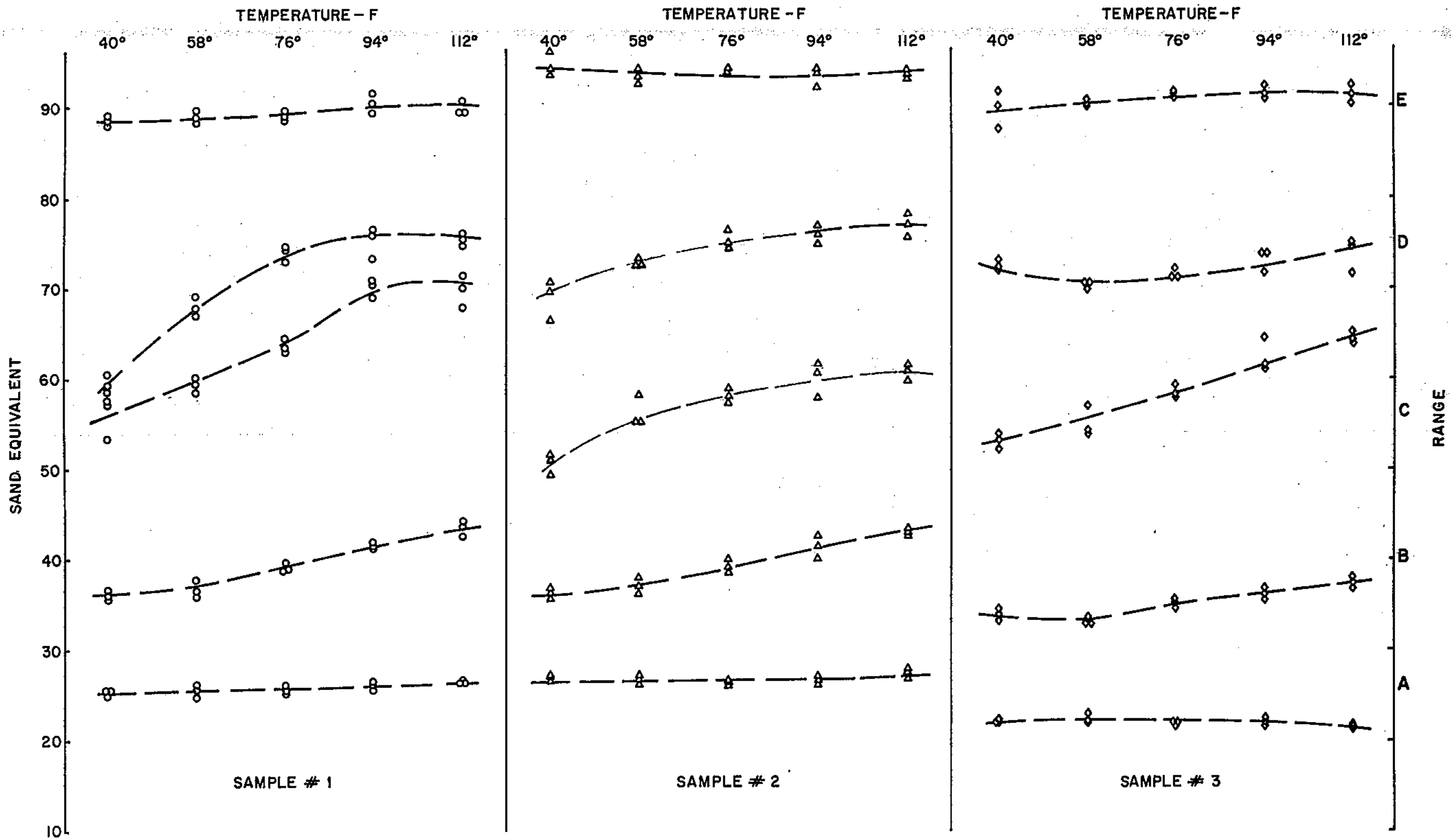

S.E. VS. MOISTURE CONDITION
SAND EQUIVALENT VALUE
RANGE E MATERIALS
100
90
80
RANGE D MATERIALS
80
70
60
RANGE C MATERIALS
60
50
RANGE B MATERIALS
40
30
RANGE A MATERIALS
30
20
DRY
FLUFF
CAST
SATURATED
OVEN AIR
SAMPLE #1
SAMPLE #2
SAMPLE #3
SAMPLE #1
SAMPLE #2
SAMPLE #3

Figure 2

SAND EQUIVALENT vs TEMPERATURE CHANGE — OVEN DRIED MATERIALS



SAND EQUIVALENT vs TEMPERATURE CHANGE – MOIST MATERIALS

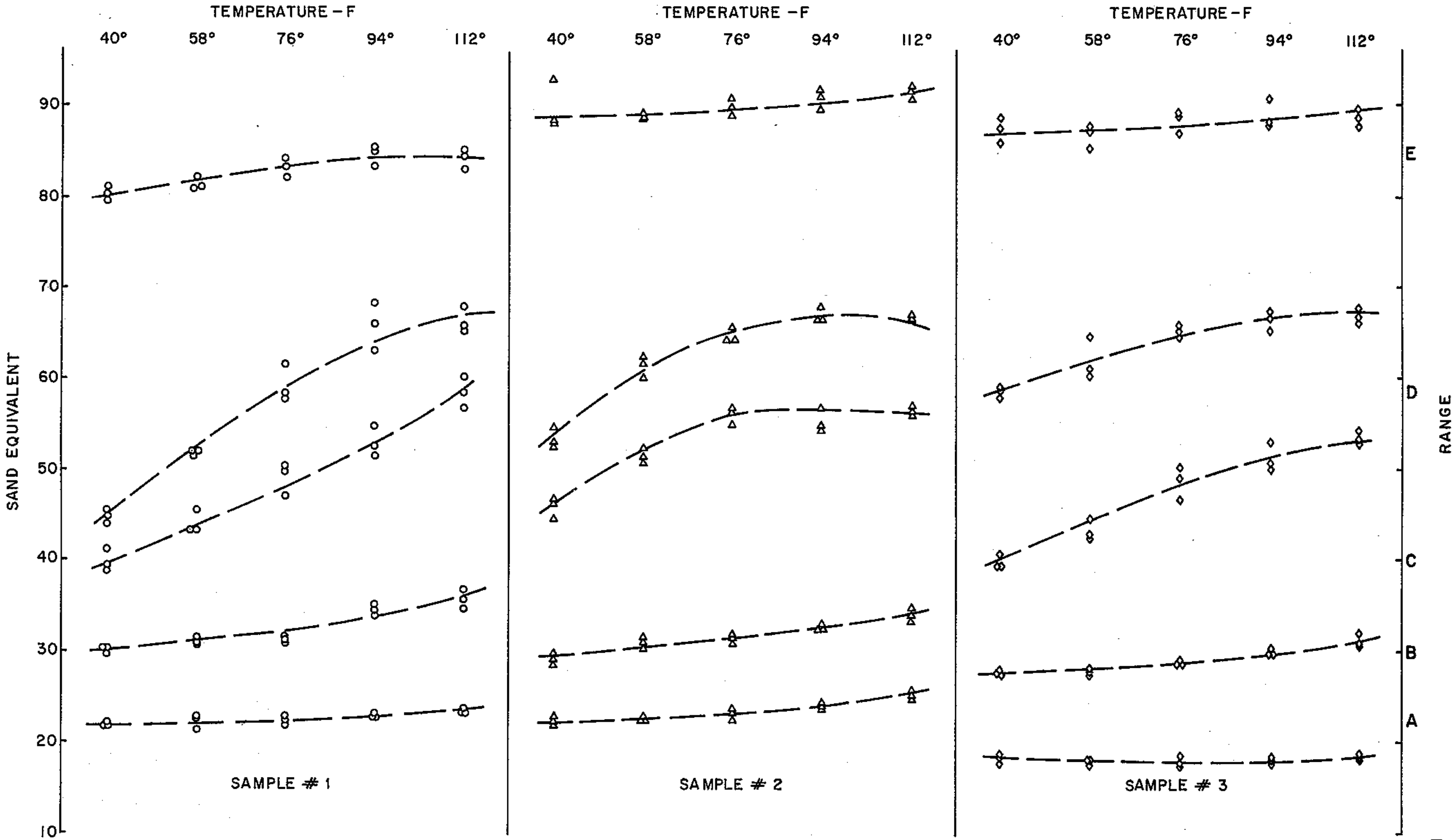


Figure 3

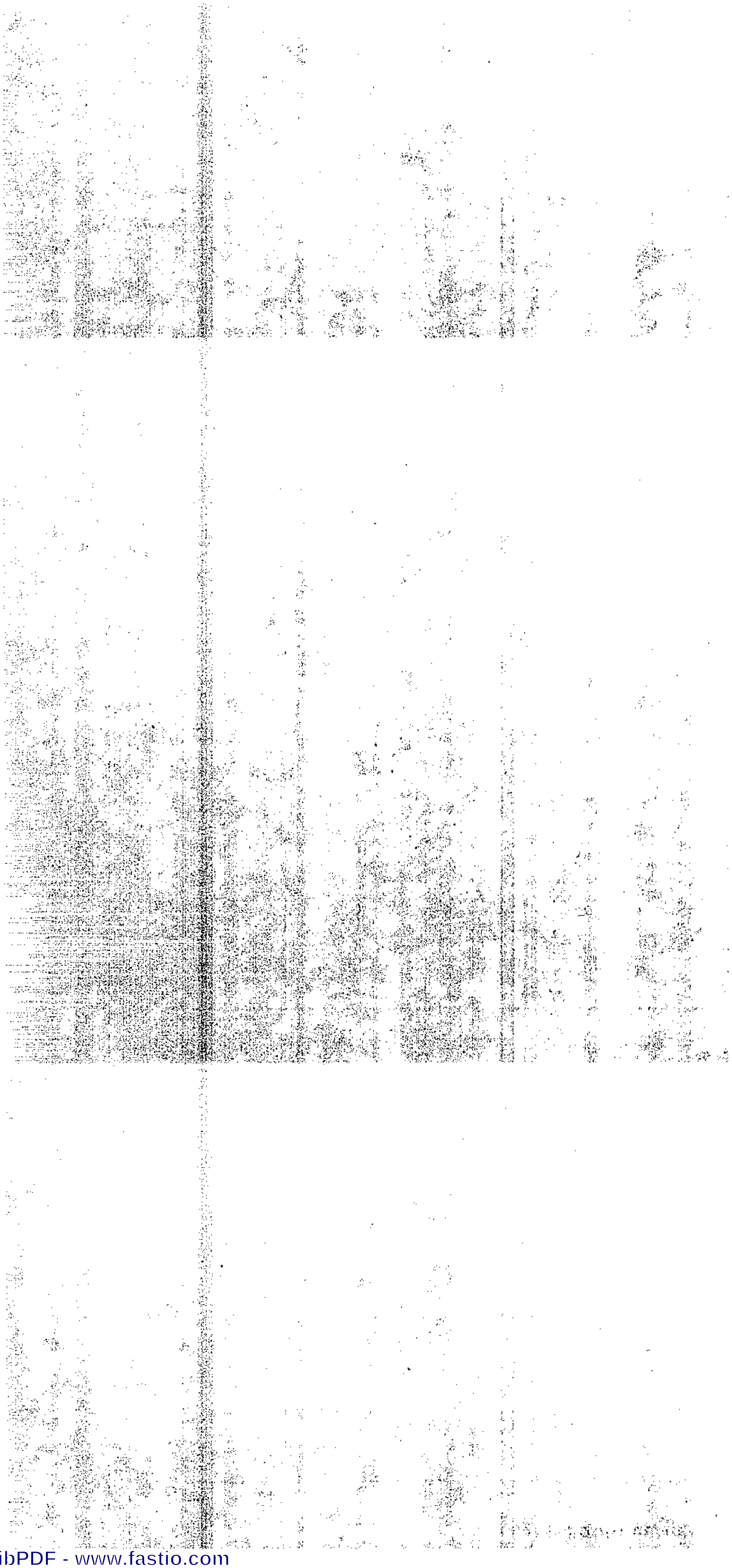


Table 1. Phase I Test Results

Sample Range	Sample Number	Range of S. E. Values for 1/4 Hr. to 2 Hr. Cure: Oven Dry	Fluff	Cast	Sat.	7 Day
A	1	26	23-24	22-23	26-27	26
	2	27	23-24	24-24	25-26	26
	3	22	19-20	19-19	22-24	21
B	1	40	36-37	35-36	34-34	33
	2	40	34-36	33-34	33-34	34
	3	36	30-31	31-31	33-34	33
C	1	61	54-56	52-54	53-54	50
	2	62	54-56	55-56	52-52	51
	3	55	48-50	47-48	47-48	47
D	1	68	60-61	63-64	62-63	62
	2	76	66-68	62-67	63-65	66
	3	73	61-66	68-69	66-67	63
E	1	90	85-86	83-86	82-86	85
	2	94	89-91	90-91	91-91	91
	3	91	89-89	89-89	87-89	88

S. E. values represent the average of three replications.

Table 2. Phase II Test Results

Sample Range	Sample Number		Ambient Temp - F° 40°	58°	76°	94°	112°
A	1	Oven Dry	26	26	26	27	27
		Wet	22	23	23	24	24
	2	Oven Dry	27	27	27	27	28
		Wet	23	23	24	25	26
	3	Oven Dry	22	23	22	22	22
		Wet	19	19	19	19	19
B	1	Oven Dry	37	37	40	42	44
		Wet	31	32	32	35	36
	2	Oven Dry	37	37	40	42	43
		Wet	30	32	32	33	35
	3	Oven Dry	34	34	36	37	38
		Wet	28	29	29	31	32
C	1	Oven Dry	57	60	64	71	70
		Wet	42	45	50	54	59
	2	Oven Dry	51	56	58	61	62
		Wet	47	52	57	56	57
	3	Oven Dry	53	55	59	63	65
		Wet	41	44	49	52	54
D	1	Oven Dry	59	68	75	76	76
		Wet	45	53	60	67	68
	2	Oven Dry	69	75	76	76	77
		Wet	54	54	66	68	68
	3	Oven Dry	73	72	72	74	74
		Wet	58	63	66	67	68
E	1	Oven Dry	89	89	90	91	91
		Wet	80	82	84	86	85
	2	Oven Dry	95	94	94	94	94
		Wet.	90	89	90	91	92
	3	Oven Dry	90	90	92	92	91
		Wet	88	88	89	89	89

S. E. values represent the average of three replications.

Table 3. Effect of Moisture Condition and Curing Time on Sand Equivalent

Source of Variation	Degrees of Freedom	Mean Squares by Range A	B	C	D	E
Samples	2	178.8	121.7	436.8	173.1	312.9
Moisture Conditions	2	100.8	4.789	53.27	21.90	2.741
Moisture x Samples Interaction	4	3.139	23.06	13.80	7.290	1.156
Curing Times	3	0.01392	0.9474	6.283	12.76	2.793
Curing x Samples Interaction	6	1.667	1.280	5.492	8.657	4.390
Curing x Moisture Int.	6	1.299	0.5874	3.722	25.03	1.425
Cur. x Moist. x Samples Int.	12	1.808	1.401	3.626	15.77	1.211
Testing Error	72	0.2068	0.3442	1.139	0.7576	0.5741

Source of Variation	F Ratios by Range A	B	C	D	E
Samples	865**	354**	383**	228**	545**
Moisture Conditions	32.1**	<1	3.86	3.00	2.37
Moisture x Samples Inter.	15.2**	67.0**	12.1**	9.62**	2.01
Curing Times	<1	<1	1.14	1.47	<1
Curing x Samples Interaction	8.06**	3.72**	4.82**	11.4**	7.65**
Curing x Moisture Int.	<1	<1	1.03	1.59	1.18
Curing x Moist. x Samples Int.	8.74**	4.07**	3.18**	20.8**	2.11*

*Significant F-Ratio **Highly Significant F-Ratio

Table 4. Effects of Ambient Temperature on Sand Equivalent
(Oven-Dried Test Specimens)

Source of Variation	Degrees of Freedom	Mean Squares by Range A	B	C	D	E
Samples	2	97.38	93.52	178.9	46.50	73.94
Temperature	4	.3064	57.94	217.3	114.8	1.449
Lineal Effect	1	.6934	223.4	850.1	399.8	4.139
Quadratic "	1	.2229	4.126	8.960	56.13	.0229
Cubic "	1	.0071	3.640	7.056	.1068	1.627
Quartic "	1	.3023	.5790	3.186	3.229	.0084
Sample x Temperature Interaction	8	.5554	1.723	6.045	34.48	1.537
Testing Error	30	.1796	.4124	2.214	1.752	.8627

Source of Variation	F-Ratios by Range A	B	C	D	E
Samples	542**	227**	80.8**	26.5**	85.7**
Temperature	<1	33.6**	36.0**	3.33	<1
T Lineal	1.24	129.6**	140.6**	11.6**	2.69
T Quadratic	<1	2.39	1.48	1.63	<1
T Cubic	<1	2.11	1.17	<1	1.06
T Quartic	<1	<1	<1	<1	<1
Samples x Temperature Interaction	3.09*	4.18 **	2.73*	19.7**	1.78
Grand Mean	24.46	37.60	59.63	71.97	91.02

*Significant F-Ratio **Highly Significant F-Ratio

APPENDIX

Sample Preparation Method

Prepare the desired number of test specimens from the sample as follows:

Maintaining a free-flowing condition, dampen the material sufficiently to prevent segregation or loss of fines.

Split or quarter out 1000 to 1500 g. of the material. Begin adding moisture to this split or quartered portion by mixing the material with a hand trowel in a circular pan while rotating the pan horizontally beneath a fine water spray. Continue mixing for one minute after the water has been added.

Continue this procedure until the material will form a firm cast when firmly squeezed in the hand. At this condition the cast will reamin intact after the hand is fully open and requires an obvious jar or touch to break it.

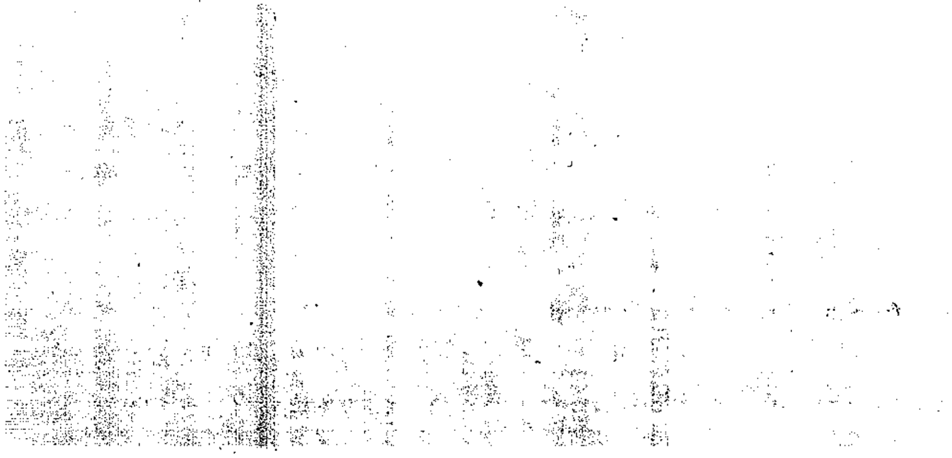
Cover the pan of material with a lid or with a damp towel which does not touch the material and allow it to stand for a minimum of fifteen minutes.

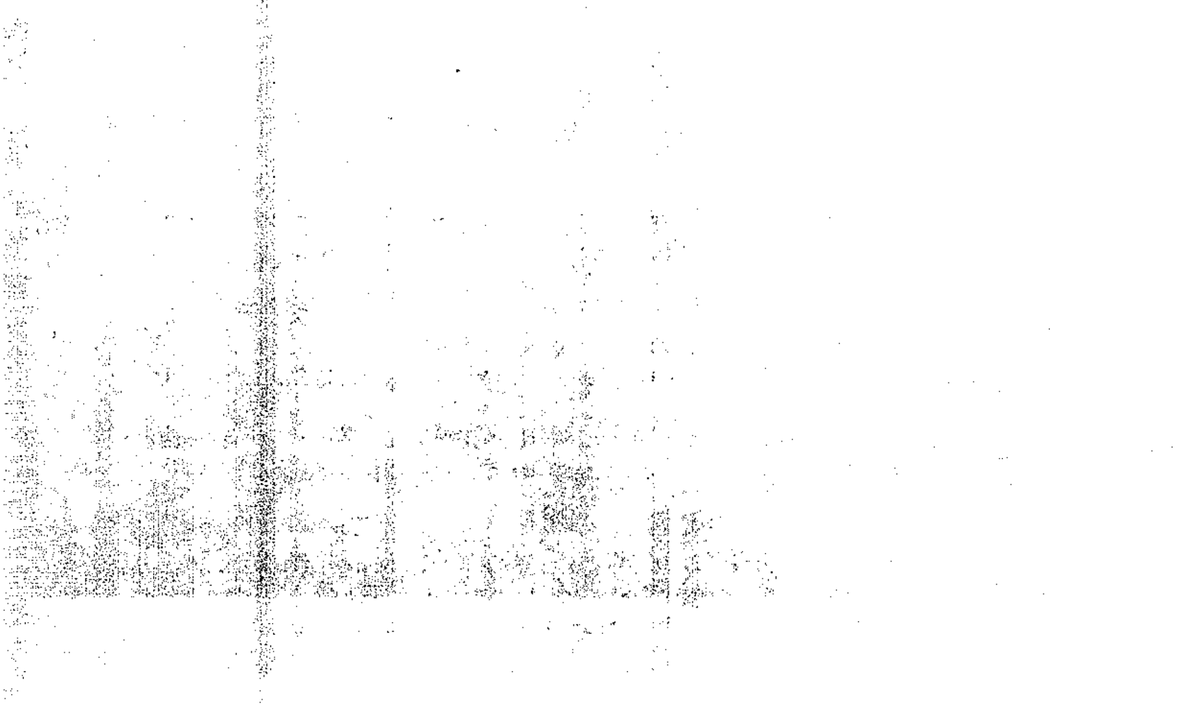
After the minimum curing time, remix for one minute without water. When thoroughly mixed, form the material into a cone with a trowel.

Take the tin measure in one hand and push it directly through the base of the pile while holding the free hand firmly against the pile opposite the measure.

As the can travels through the pile and emerges, hold enough hand pressure to cause the material to fill the can to overflowing. Press firmly with the palm of the hand, compacting the material until it consolidates in the can.

The excess material should be struck off level with the top of the can, moving the edge of the trowel in a sawing motion across the brim.





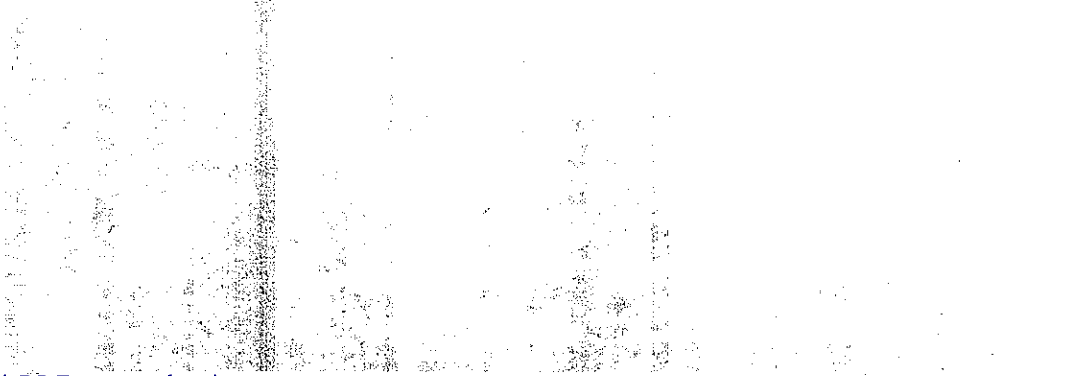


Table 5. Effects of Ambient Temperature on Sand Equivalent (Moist Test Specimens)

Source of Variation	Degrees of Freedom	Mean Squares by Range A	B	C	D	E
Samples	2	126.8	46.24	132.3	153.2	214.7
Temperature	4	3.623	31.98	288.2	348.1	13.37
Lineal Effect	1	13.00	122.3	1124	1292	47.38
Quadratic Effect	1	1.468	3.467	22.13	98.85	.0350
Cubic Effect	1	.0284	.0360	.1778	1.469	5.675
Quartic Effect	1	.0001	2.150	6.914	.2724	.3764
Sample x Temperature Interaction	8	.9746	1.314	12.42	29.50	1.551
Testing Error	30	.2178	.2858	1.640	1.442	1.537

Source of Variation	F-Ratios by Range A	B	C	D	E
Samples	582**	162**	80.7**	106**	139**
Temperature	3.72	24.3**	23.2**	11.8**	8.61**
T Lineal	13.34**	93.1**	90.4**	43.8**	30.5**
T Quadratic	1.51	2.64	1.78	3.35	< 1
T Cubic	< 1	< 1	< 1	< 1	3.66
T Quartic	< 1	1.64	< 1	< 1	< 1
Sample x Temperature Interaction	4.48**	4.60**	7.58**	20.5**	1.01
Grand Mean	21.35	31.09	49.76	61.49	86.95

*Significant F-Ratio **Highly Significant F-Ratio